CONTRACT AF 33(616)-8438
PROJECT 7381, TASK 738103

POLYETHYLENE TEREPHTHALATE

Data Sheets

John T. Milek

DS-105
June 1962

EPIC

HUGHES

HUGHES AIRCRAFT COMPANY
CULVER CITY, CALIFORNIA

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FOREWORD

This report was prepared by Hughes Aircraft Company under Contract No. AF 33(616)-8438. The contract was initiated under Project No. 7381, Task No. 738103. The work was administered under the direction of the Directorate of Materials and Processes, Aeronautical Systems Division, with Mr. R.F. Klinger acting as Project Engineer.

Many persons have contributed to the program which this report represents. The author wishes especially to acknowledge the contributions of the following: J.J. Anders, J.W. Atwood, C.L. Blocher, D.L. Grigsby, F.S. Harter, D.H. Johnson, H.T. Johnson, M.S. Neuberger, and E. Schafer.

ABSTRACT

The Electronic Properties Information Center has been established to collect, index and abstract the literature on the electrical and electronic properties of materials and to evaluate and compile the experimental data from that literature. A modified coordinate index to the literature is machine stored and printed for manual use. The Center publishes data sheets, summary reports, thesauri, glossaries, and similar publications as sufficient information is evaluated and compiled. This report consists of the compiled data sheets on Polyethylene Terephthalate.

This report has been reviewed and is approved for publication.

H. Thayne Johnson
H. Thayne Johnson, Supervisor
Electronic Properties Information Center

John W. Atwood
John W. Atwood
Project Manager

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INTRODUCTION

In June 1961, a program was initiated under the direction of the Air Force to collect, index and abstract the literature on the electrical and electronic properties of materials and to evaluate and compile the experimental data from that literature. Placed at Hughes Aircraft Company in Culver City, California, the program, now called the Electronic Properties Information Center, was originally intended to cover ten major categories of materials: Semiconductors, Insulators, Ceramics, Ferroelectrics, Metals, Ferrites, Ferromagnetics, Electroluminescent Materials, Thermionic Emitters, and Superconductors.

During the first year, studies were completed on the Semiconductor and Insulator categories; and Ceramics was discontinued as a separate category and subsumed under the other nine. Vocabulary studies have now been completed on all categories, and retrospective documentation is virtually complete for Semiconductors and Insulators. A full index to the literature is maintained; and publications such as data sheets, summary reviews, glossaries, and thesauri are periodically issued. The use of the Center and these publications are available to anyone wishing information within the scope of the Center's objectives. A full list of publications to date appears at the end of this report.

This report contains data sheets on Polyethylene Terephthalate. The data sheets have been compiled direct from the literature. Articles are allowed to accumulate in the system until it is judged that a sufficient number are available on one material for adequate evaluation. The manual modified coordinate index is then used to retrieve all literature on the material to be compiled. Bibliographies are checked to make sure that valuable and relevant literature is not overlooked. Then the assembled literature is given to the specialist doing the evaluation and compilation.

Evaluation is confined to primary source data except when only secondary citations are available. If equally valid data are available from several sources, all are given. Data are rejected when judged questionable because of faulty or dubious measurements, unknown sample composition, or if more reliable data are available from another source. Selection of data is based upon that which is judged most representative, precise, reliable, and covers the widest range of variables. The addition of new data to a previously evaluated property requires a reappraisal of the reported values. Older data may be deleted if the new data are judged more accurate or representative.

After a thorough analysis and evaluation, the data is compiled into data sheets which present it in its most optimum form. This will be, primarily, but not limited to, curves or tabular form. Where possible, graphs are adapted directly from the original sources. If this is not possible, they are drawn from data compiled from the articles. Where thought important, notes are entered with each graph to help the user.

The references, from which the data are drawn, are shown by reference number below each graph with the full bibliographic information at the end of the data sheets. The bibliography is referred to and listed in the order of entry into the Center (accession Number). This provides a quick cross reference into the index used with the literature.

These data sheets were originally issued in loose leaf form in June 1962. In response to numerous additional requests for copies, they are being reissued at this time.

This compilation deals only with Polyethylene Terephthalate as an Insulator. Non-insulator data will be included in a future revision.

MATERIALS DESCRIPTION

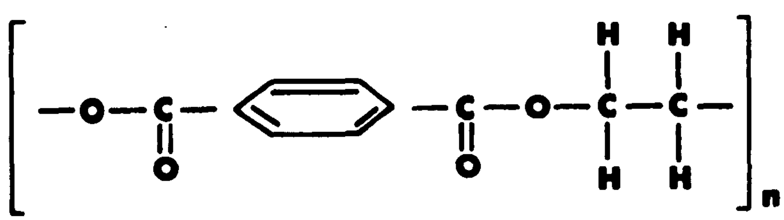
Polyethylene Terephthalate (Mylar) is a thermoplastic, linear polyester type of plastic material. Mylar is the registered trade name of material made by the E.I. Du Pont Company. Other known trade names are Terylene, Terafilm, and Videne. Mylar is available in fiber form (under the name of Dacron) and films of various thicknesses and grades:

Type A - General purpose and electrical film

Type C - For capacitor applications requiring high temperature insulation resistance

Type D - Highly transparent film with a minimum number of surface defects

The resin is produced by the esterification of ethylene glycol and terephthalic acid and is two-dimensional in structure. It has the following molecular structure:



where n signifies repetition of the monomer unit several thousand times.

The film is oriented so that the properties are uniform in all directions of the sheet. Most properties of the film are dependent upon this orientation. The films are tough; and when heated to approximately 135°C, they exhibit a heat shrinkage. At 150°C they shrink rapidly and embrittle.

Mylar materials are widely used as sheets and tapes for insulating capacitors, coils, motors, transformers, and electronic equipment. The film is used extensively as the dielectric film in Mylar capacitors.

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POLYETHYLENE TEREPHTHALATE

Corona Effects

Property	Film Thickness, Mils	Value	
		Untreated	Treated
Corona Resistance	2	1065 min/mil	1195 min/mil

Table 1.1 Corona resistance of untreated 2 mil thick Mylar compared with Mylar treated with toluene diisocyanate vapor. [Ref. 7]

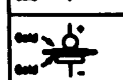
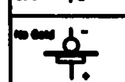
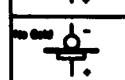
	Heptane	5~6 [illegible]	No corona
	Air	4~6	Large corona
	Heptane	6~7	No corona
	Air	5~6	Large corona
	Heptane	5~6	No corona
		2~4	Small corona
		3~4	Small corona
		2~4	Small corona
		3~4	Small corona

Table 1.2. Electrode and moisture effects on corona resistance. [Ref.5]

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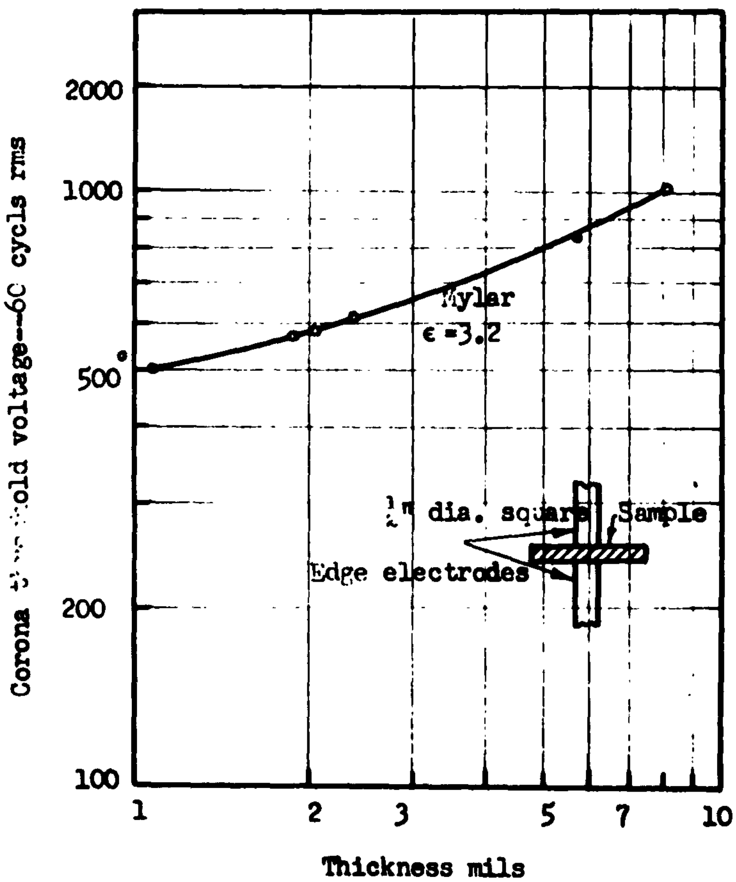
POLYETHYLENE TEREPHTHALATE

<u>Corona Effects</u>



(Sample held between 1/2" diam. square edge electrodes.)

Figure 1.1. Corona threshold voltages on dielectric surfaces. [Ref. 3]

POLYETHYLENE TEREPHTHALATE

Corona Effect

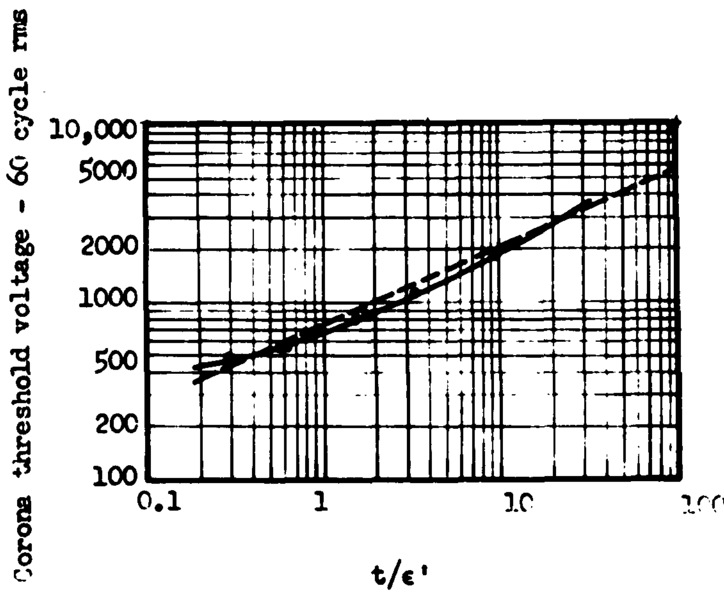


Figure 1.2. Corona threshold voltages on dielectric surfaces as a function of thickness/dielectric constant. (Dashed line is $V = 720\ (t/\epsilon')^{0.46}$, where t = thickness in mils, and ϵ' = dielectric constant = 3.2) [Ref. 3]

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POLYETHYLENE TEREPHTHALATE

Dielectric Constant

Frequency	Temperature	ε'
60 cps	25°C (77°F) 150°C (300°F) 155°C (311°F)	3.2 3.7 2.67
1 kc	25°C (77°F) 100°C (212°F)	3.1 2.62
1 mc	25°C (77°F) 155°C (311°F)	3.0 2.88

Table 2.1. Dielectric constant as a function of temperature and frequency. [Ref. 6]

(Samples measured at 1 kc. and 25°C.)

Temp., °C	Atmos., %RH	Time, Days	Dielec. Const.
100	Dry	8 49	3.33 3.29
	75	8 23 49	3.30 3.27 3.30
90	Dry	8 91	3.35 3.20
	75	8 23 50	3.33 3.40 3.30
Before exposure			3.35

Table 2.2. Effect of heat, moisture, and ageing on dielectric constant. Accuracy of data = ± 1.0%. [Ref. 8]
10-mil Mylar sheet.

POLYETHYLENE TEREPHTHALATE

Dielectric Constant

Integrated Dosage, Rads		
Measurement	Average of 10	Dielectric Constant
0	Average S	3.04 0.065
10^7	Average S t	2.98 0.046 2.323
10^8	Average S t	3.01 0.031 1.416
10^9	Average S t	3.02 0.097 0.576

Material: Mylar Type A, 2-mils thick.
No. of specimens: Average of 10 per point.
Radiation: 2 mev electrons at a rate of 10^4 rads/minute.
Statistics: Significance of difference between the means of nonirradiated and irradiated material exists when t (for 18 degrees of freedom) exceeds 2.101, for a significance level of $\pm$ 2.5%.

S - Standard Deviation
t - "t" test, an indication of the statistical significance between the corresponding irradiated and unirradiated groups.

Table 2.3. Effect of radiation dosage on dielectric constant. [Ref.1]

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POLYETHYLENE TEREPHTHALATE

Dielectric Constant

Integrated Dosage, Rads	Dose rate, 10^4 Rads/min.			Dose rate, 10^7 Rads/min.		
	Dielectric Constant	S	t	Dielectric Constant	S	t
0	3.04	0.065		3.04	0.065	
10^7	2.98	0.0455	2.323	3.03	0.0660	0.200
10^8	3.01	0.0306	1.416	2.97	0.0497	2.804
10^9	3.02	0.0969	0.576	3.04	0.0548	0.000

Material: Mylar, Type A, 2 mils thick.
No. of specimens: Average of 10 samples per point.
Radiation: 2 mev electrons.
Voltage stress: 300 volt/second rise, rms, 60 cycles per second.
Statistics: Significance of difference between the means of non irradiated and irradiated material exists when t (for 18 degrees of freedom) exceeds 2.101, for a significance level of $\pm$ 2.5%

S - Standard Deviation.
t - "t" test, an indication of the statistical significance between the corresponding irradiated and unirradiated groups.

Table 2.4. Effect of dose rate and dosage on dielectric constant. [Ref.1]

POLYETHYLENE TEREPHTHALATE

Dielectric Constant

	Dosage, Rads		
Ambient	10^7	10^8	10^9
Air[1]	3.03	2.98	3.04
Air	2.99	2.98	3.04
Helium	3.02	2.96	3.09
Oxygen	2.99	2.98	3.03

Material: Mylar Type A, 2 mils thick.
No. of specimens: Average of 10 per point.
Radiation: 2 mev electrons at 10^7 rads/minute.
2-mil Mylar stored for 90 days in the ambient atmosphere indicated.

[1]Measurements taken 24 hours following irradiation.

Table 2.5. Postirradiation effects in oxidizing and inert ambients upon dielectric constant of Mylar. [Ref. 1]

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POLYETHYLENE TEREPHTHALATE

<u>Dielectric Constant</u>

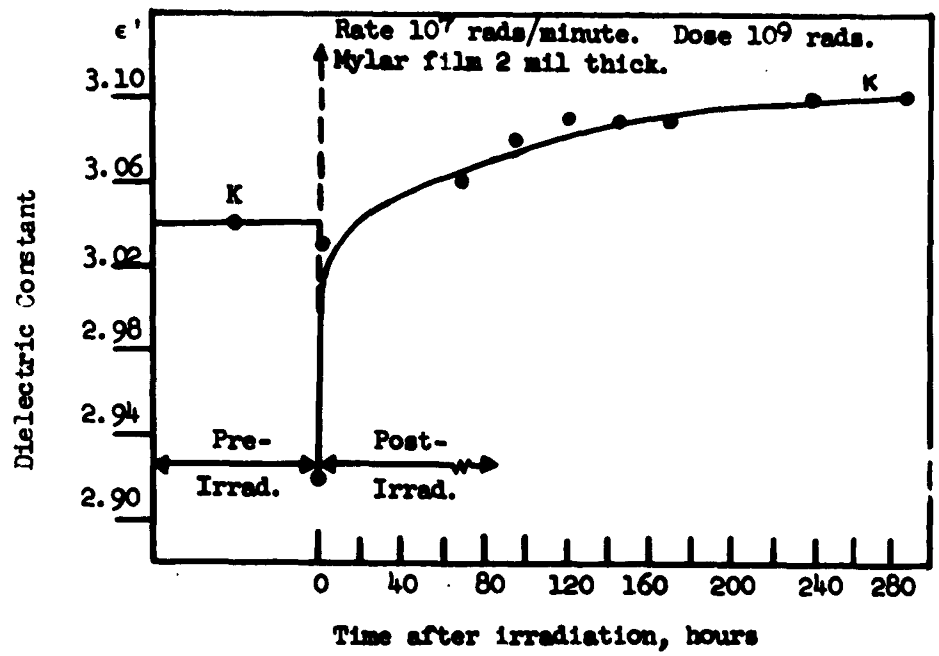

Figure 2.1. Postirradiation effects on dielectric constant. [Ref. 1]

POLYETHYLENE TEREPHTHALATE

Dielectric Constant

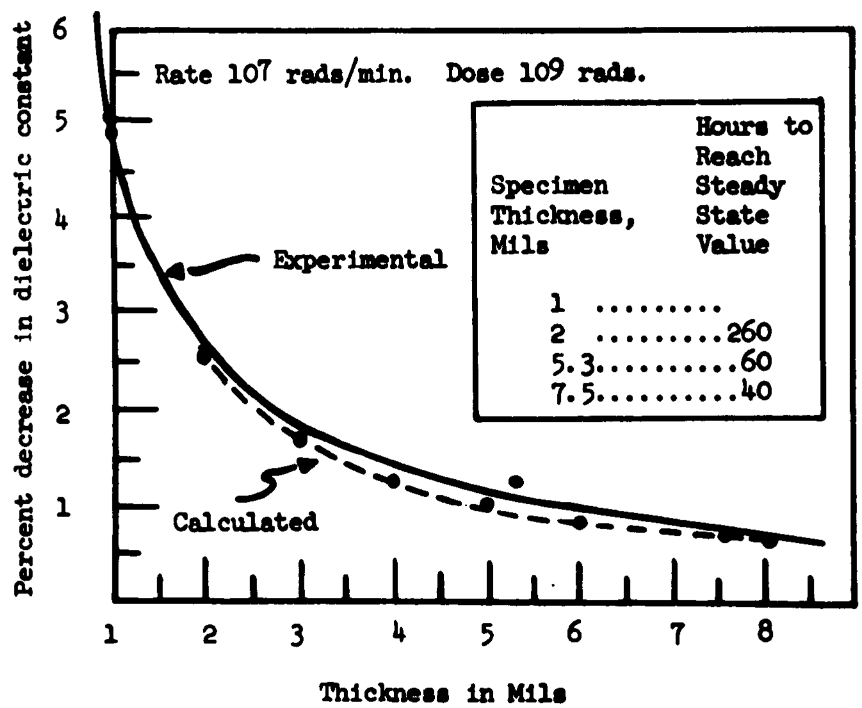

Figure 2.2. Percent decrease in dielectric constant immediately following irradiation as a function of thickness. [Ref. 1]

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POLYETHYLENE TEREPHTHALATE

Dielectric Strength

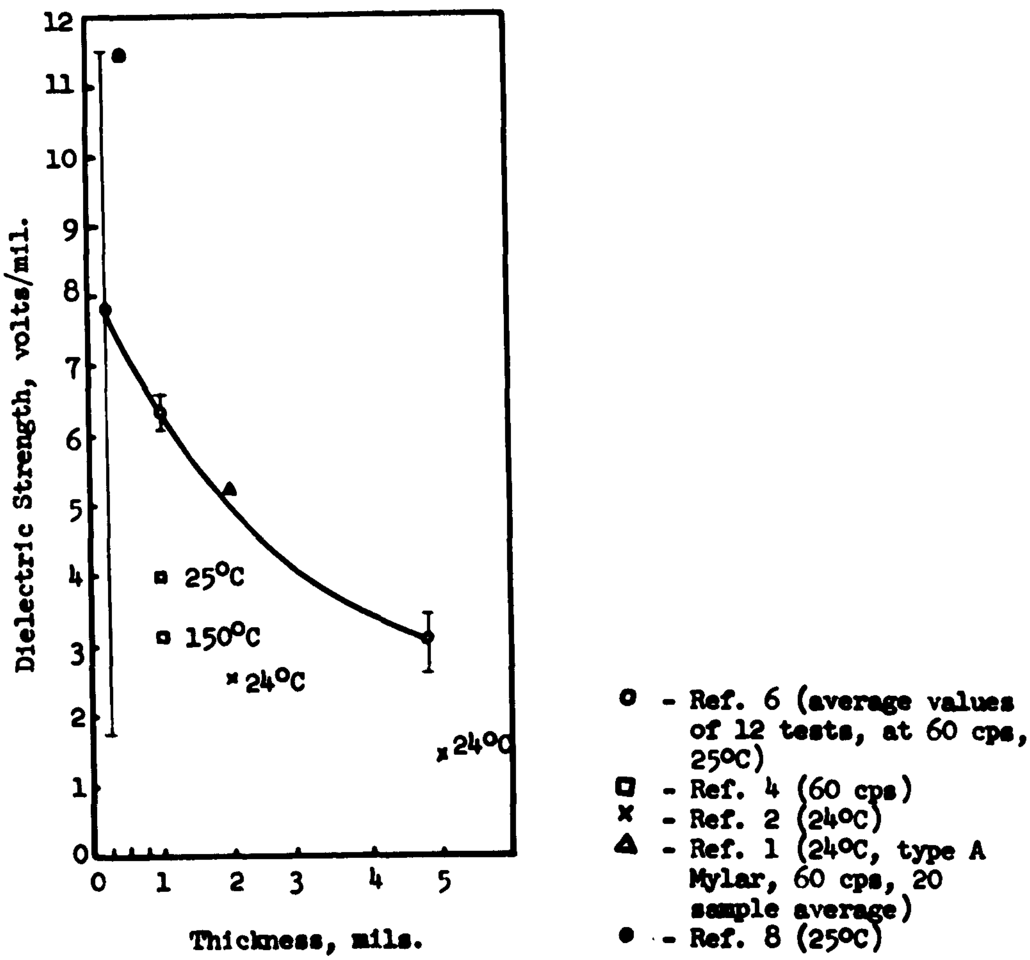

Figure 3.1. Dielectric Strength as a function of thickness.

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POLYETHYLENE TEREPHTHALATE

Dielectric Strength

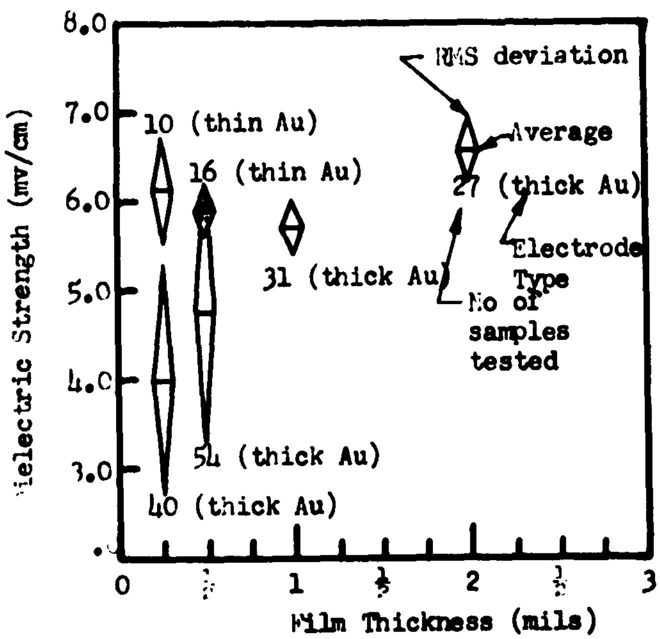

Figure 3.2. Dielectric strength as a function of thickness at 23°C. [Ref. 5]

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POLYETHYLENE TEREPHTHALATE

Dielectric Strength

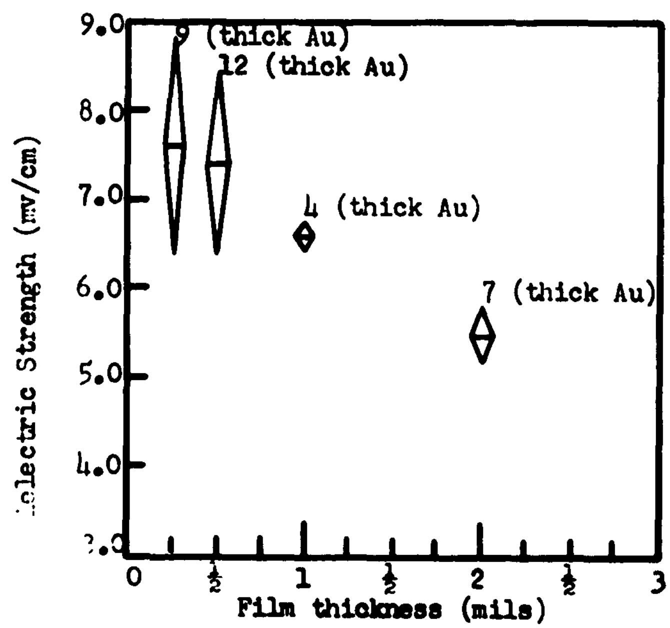
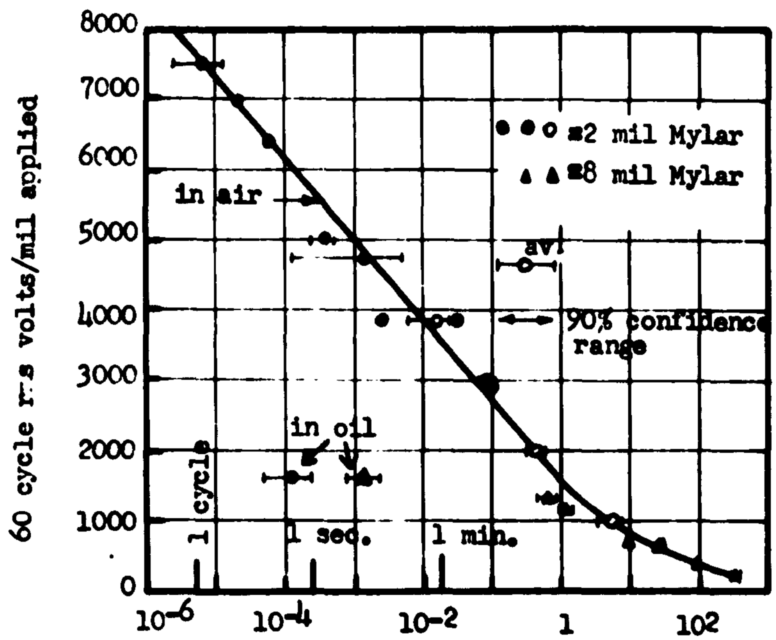


Figure 3.3. Dielectric strength as a function of thickness at -180°C. [Ref. 5]

POLYETHYLENE TEREPHTHALATE

Dielectric Strength



Note: Straight rise (2 kv/sec) breakdown strength of 2 mil Mylar film, 4800 v/mil (in air)

Figure 3.4. Variation of dielectric strength with time. [Ref. 3]

POLYETHYLENE TEREPHTHALATE

<u>Dielectric Strength</u>

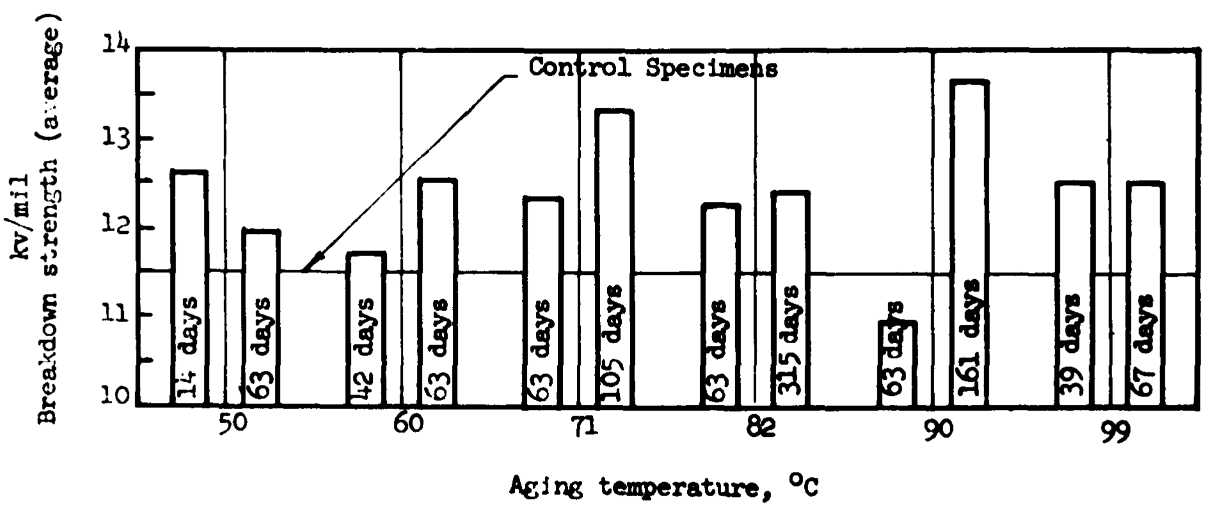


Figure 3.5. Aging of 0.5 mil thick, Grade C du Pont Mylar in air, (Data average of 20 samples.) [Ref. 8]

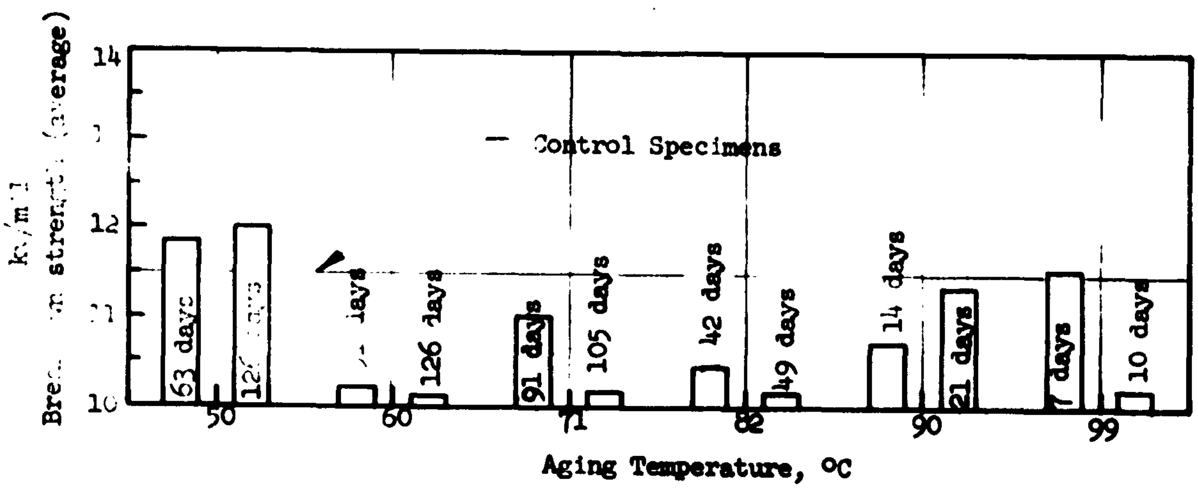


Figure 3.6. Aging of 0.5 mil thick, Grade C du Pont Mylar in water, (Data average of 20 samples.) [Ref. 8]

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POLYETHYLENE TEREPHTHALATE

Dielectric Strength

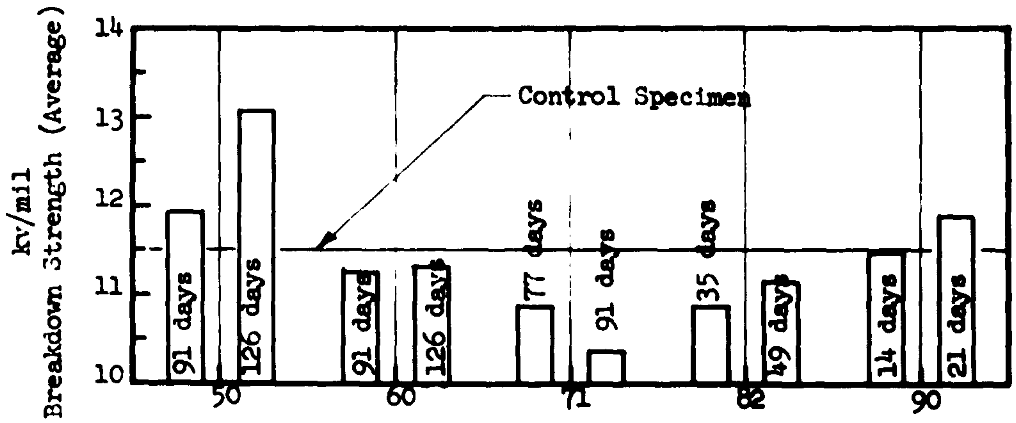

Figure 3.7. Aging of 0.5 mil thick, Grade C du Pont Mylar 95% rel. humidity, (Data average of 20 samples.) [Ref. 8]

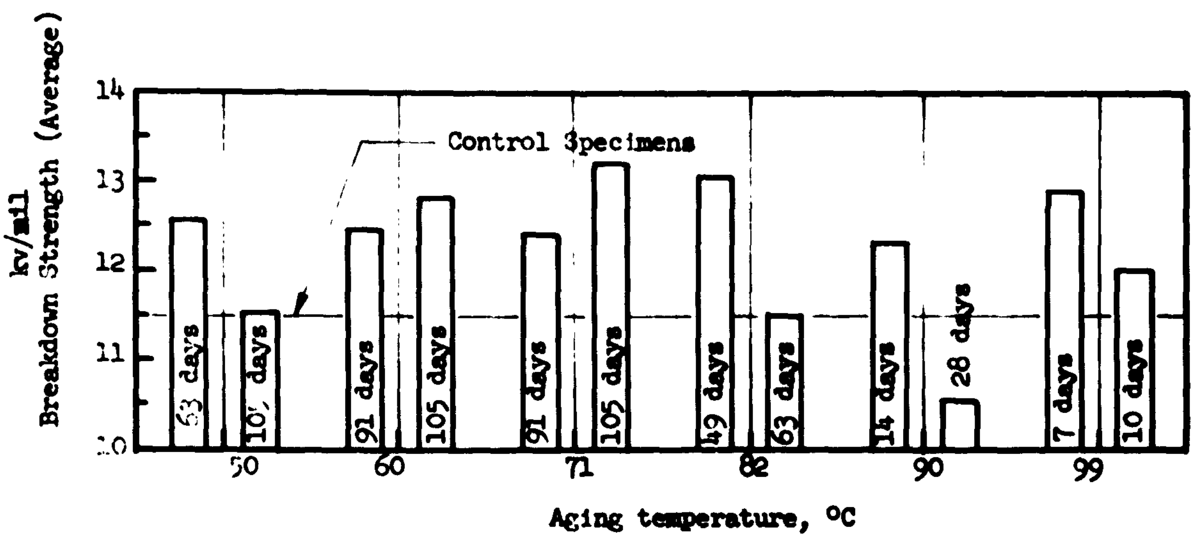

Figure 3.8. Aging of 0.5 mil thick, Grade C du Pont Mylar in 75% rel. humidity, (Data average of 20 samples.) [Ref. 8]

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Dielectric Strength

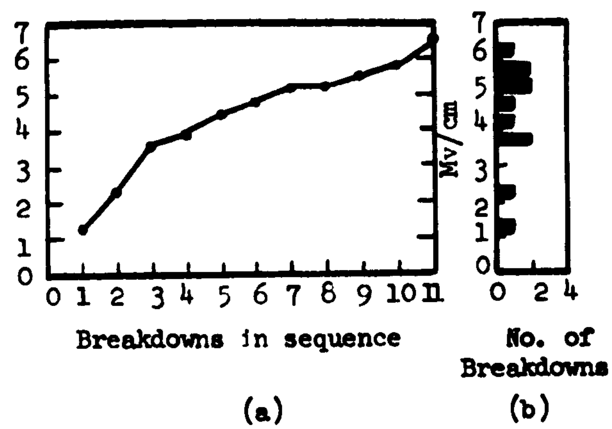

Figure 3.9. (a) Breakdown sequence and (b) histogram for a single sample of 1/4-mil film (21°C) [Ref. 5]

Property	Film Thickness, Mils	Value Untreated	Value Treated
Dielectric Strength (in oil)	2	3340 v/m	3530 v/m

Table 3.1. Effect of treatment with toluene diisocyanate on dielectric strength. [Ref. 7]

POLYETHYLENE TEREPHTHALATE

Dielectric Strength

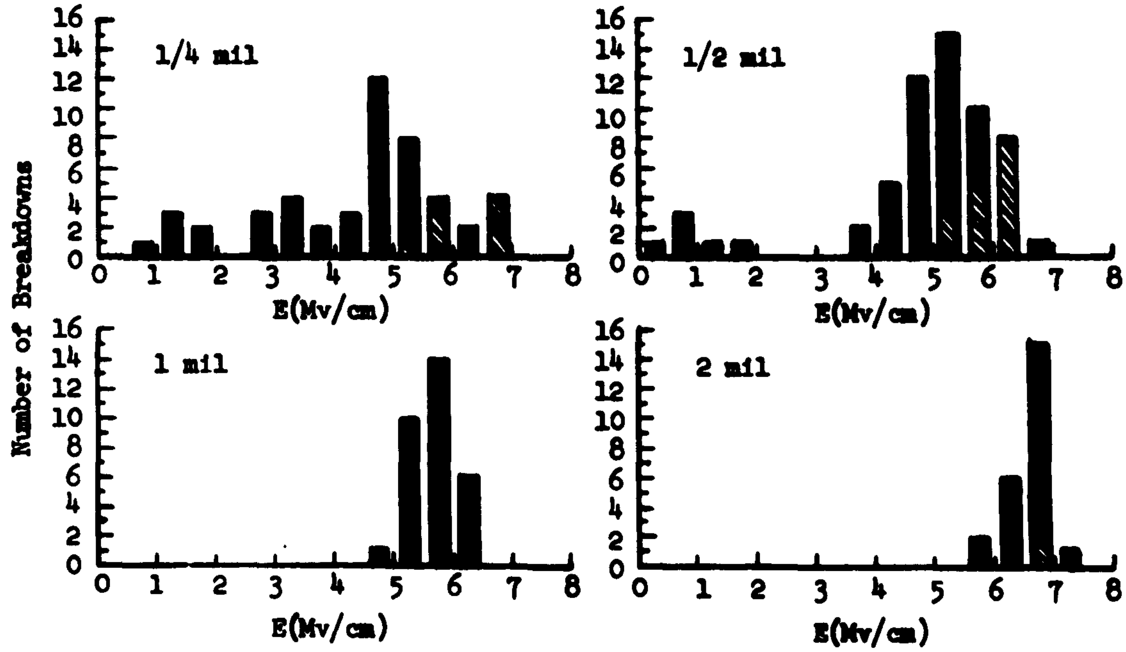

Figure 3.10. Breakdown histograms for various film thickness at 23°C. \\\\Thin (self-healing) electrodes, final value. ▬ Thick electrodes.
[Ref. 5]

POLYETHYLENE TEREPHTHALATE

Dielectric Strength

Thickness		Irradiated	Unirradiated
5 mil	D.S. %change σ S t	1478 v/mil 0.47% ± 64 v/mil ± 4.3 % 0.094	1471 v/mil ± 127 v/mil ± 8.6%
2 mil	D.S. %change σ S t	2733 v/mil 11.6% ± 220 v/mil ± 8.0% 1.749	2553 v/mil ± 218 v/mil ± 8.5%

D.S. - Average dielectric strength at breakdown.
σ - Root-mean-square deviation.
S - Coefficient of dispersion.
t - test, statistical significance of the difference between the average breakdown strength of the corresponding irradiated and unirradiated groups.

Table 32 Effect of radiation on dielectric strength (Data at 24°C) [Ref. 2]

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Dielectric Strength

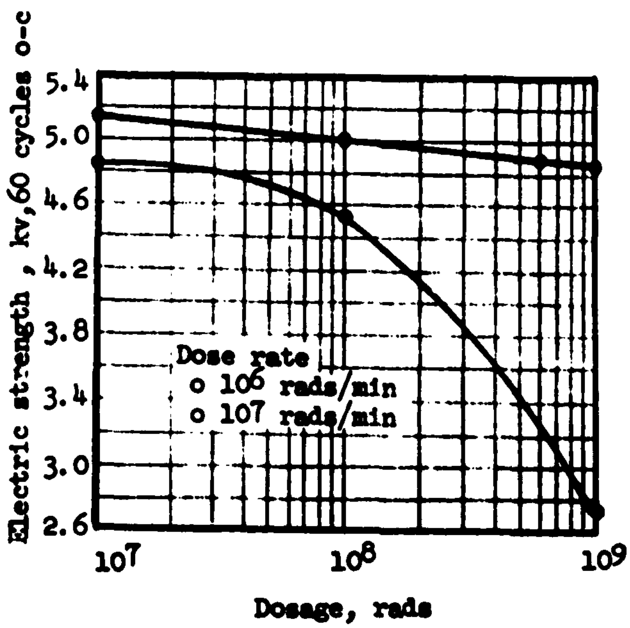

Figure 3.11. Measurements made on polyethylene terephthalate with specified dose rates for different dosages of irradiation. (DuPont type A Mylar, 2 mil thick) [Ref. 2]

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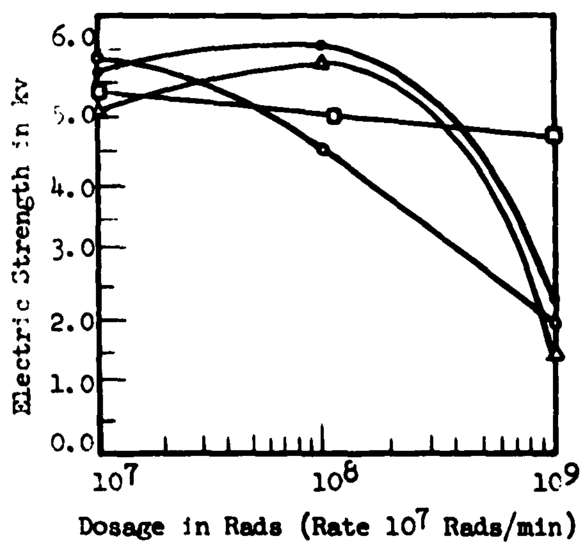
POLYETHYLENE TEREPHTHALATE

Dielectric Strength



- o Stored 90 days in oxygen.
- • Stored 90 days in air.
- □ Test immediately following irradiation.
- △ Stored 90 days in helium.

Figure 3.12. Effects of oxidizing and inert gas ambients. [Ref. 1]

POLYETHYLENE TEREPHTHALATE

Dissipation Factor

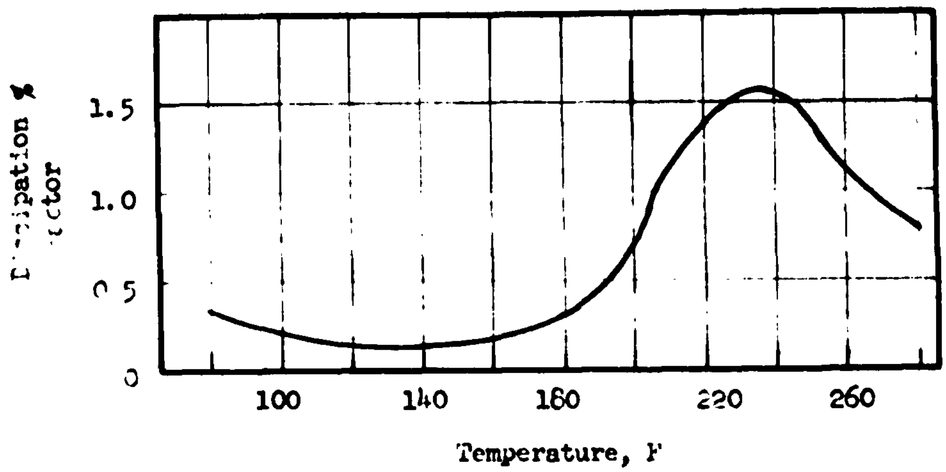
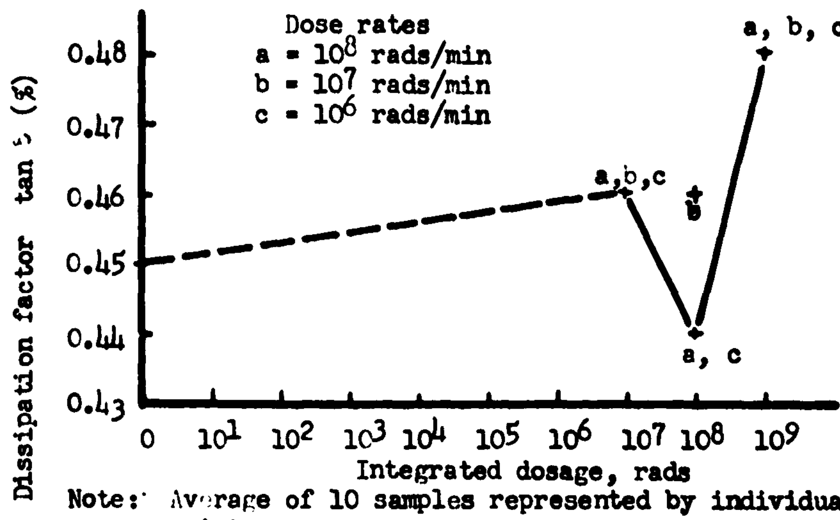


Figure 4.1. Effect of temperature on dissipation factor. [Ref. 11]

POLYETHYLENE TEREPHTHALATE

Dissipation Factor



Note: Average of 10 samples represented by individual points.

Figure 4.2. Effect on dissipation factor of radiation dosage up to 10^9 rads on du Pont type A Mylar, 2 mils thick. [Ref. 1]

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POLYETHYLENE TEREPHTHALATE

Dissipation Factor

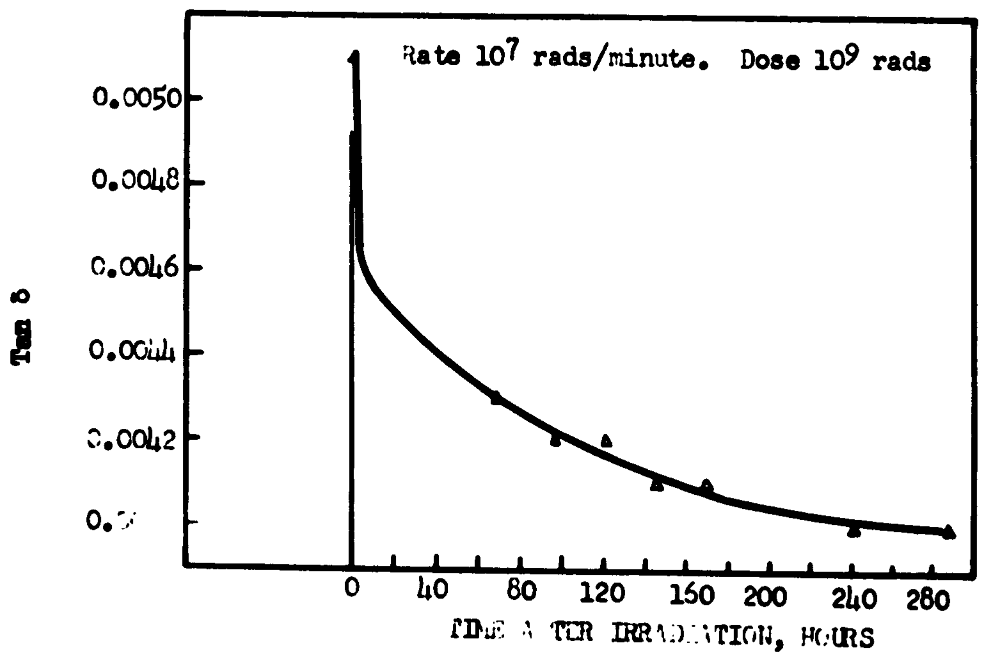

Figure 4.3. Post-irradiation effects on dissipation factor. [Ref.1] Measurements at 1000 c.p.s.

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POLYETHYLENE TEREPHTHALATE

Dissipation Factor

(Samples measured at 1 kc. and 25°C.)

Temp., °C.	Atmos., %RH	Time, Days	Tan δ
100	Dry	8 49	0.00422 0.00489
	75	8 23 49	0.00404 0.00356 0.00313
90	Dry	8 91	0.00415 0.00575
	75	8 23 50	0.00451 0.00410 0.00398
Before exposure			0.00422

Table 4.1 Effect of temperature, moisture and aging on dissipation factor. (10 mil. Mylar Sheet) [Ref 8]

POLYETHYLENE TEREPHTHALATE

Dissipation Factor

Ambient	Dosage, Rads		
	10^7	10^8	10^9
	Dissipation Factor, Per Cent		
Air[1]	0.46	0.46	0.48
Air	0.44	0.40	0.42
Helium	0.35	0.37	0.40
Oxygen	0.43	0.44	0.42

Material: Mylar Type A, 2 mils thick.
No. of specimens: Average of 10 per point.
Radiation: 2 mev electrons at 10^7 rads/minute.
2-mil Mylar stored for 90 days in the ambient atmosphere indicated.

[1]Measurements taken 24 hours following irradiation.

Table 4.2. Postirradiation effects in oxidizing and inert ambients upon dissipation factor. [Ref.]

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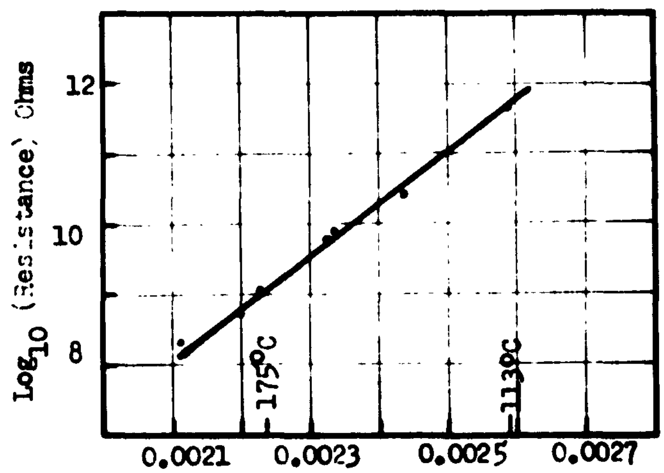
POLYETHYLENE TEREPHTHALATE

Insulation Resistance

100°C	5000 megohm mfds (.25 mil)
130°C	400 megohm mfds
150°C	100 megohm mfds (.25 mil)

Note: Data based on wound capacitor sections.

Table 5.1 Effect of temperature on Insulation Resistance. [Ref. 4] [Ref. 7]



The effect of temperature changes on the D. C. resistance of a crystalline sample is shown in which $\log_{10}R$ is plotted against reciprocal absolute temperature. The geometrical factor for conversion from resistance R to resistivity ρ is ρ/R = 260 (based on room temperature dimensions).
NOTE: Sample size = 53 mm diam. x 0.5 mm thick cut from molded sheet. Sample of I. C. I. "Terylene".

Figure 5.1. Plot of $\log_{10}$ (sample resistance) against 1/T. [Ref. 10]

POLYETHYLENE TEREPHTHALATE

Insulation Resistance

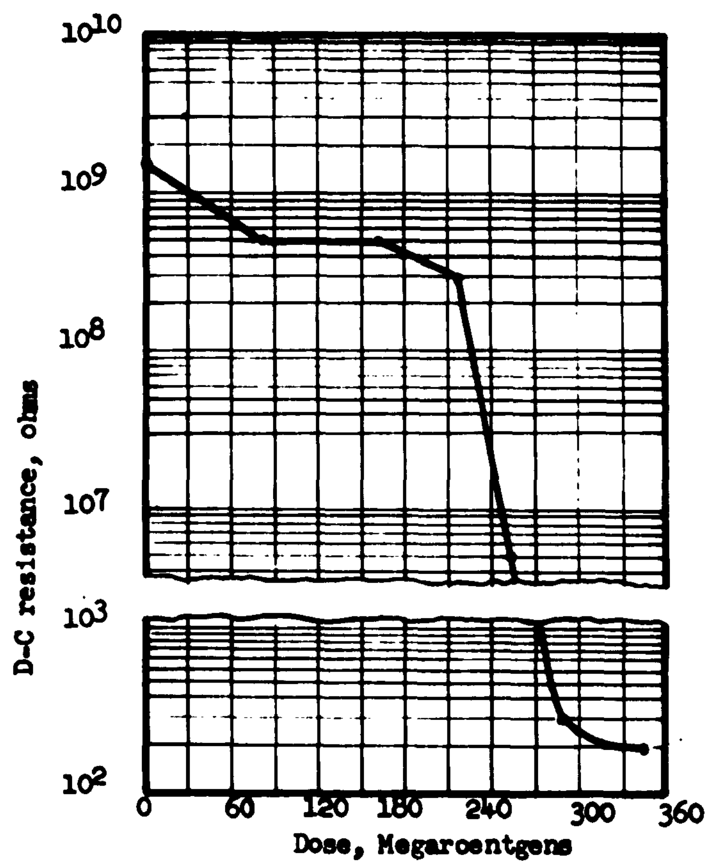


Figure 5.2. D-C resistance as a function of dosage for polyethylene terephthalate. (Specimens irradiated with the NRL Van de Graff generator with 2 mev electrons at the rate of 0.6 megaroentgens per hour over an area of about 9 sq. inches. Specimens removed from radiation field for measurement. Thickness: 0.0001 inch.) [Ref. 2]

DATA SHEET

ELECTRICAL AND ELECTRONIC PROPERTIES

MATERIALS CENTRAL
AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND

INSULATION MATERIALS

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POLYETHYLENE TEREPHTHALATE

<u>Insulation Resistance</u>

Sample No.	Ageing Conditions °C	%RH	Time, Days	Measurement Environments Insulation Resistance (in ohms) 50% RH 75° F.	2 days at 90% RH, 95°F. Max.	Min.	Average
Control		None		$>2 \times 10^{12}$	2×10^{12}	2×10^{12}	2×10^{12}
7088	80	Air	245	$>2 \times 10^{13}$	6×10^{8}	3×10^{8}	4×10^{8}
8789	90	Air	105	$>2 \times 10^{13}$	2×10^{8}	4×10^{7}	8×10^{7}
4589	90	95	35	$>2 \times 10^{13}$	3×10^{8}	5×10^{7}	2×10^{8}
5389	90	75	77	$>2 \times 10^{13}$	7×10^{8}	4×10^{8}	6×10^{8}
6588	80	95	98	$>2 \times 10^{13}$	4×10^{9}	1×10^{9}	2×10^{9}
6788	80	75	140	$>2 \times 10^{13}$	2×10^{10}	4×10^{8}	6×10^{9}
VALUES OBTAINED AFTER WASHING							
Control		None		$>2 \times 10^{13}$			$>2 \times 10^{12}$
8789	90	Air		$>2 \times 10^{13}$			$>2 \times 10^{12}$
4589	90	95		$>2 \times 10^{13}$			$>2 \times 10^{11}$

Resistance measured in accordance with ASTM method D 1202-52T after conditioning the sample at 50% RH, 75°F; and at 90% RH, 95°F. At the lower humidity and temperature, the resistance was above the range of the galvanometer.

Table 5.2. Effect of medium-temperature aging on insulation resistance. (10 mil Mylar, du Pont Grade A) [Ref. 8]

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Power Factor

Frequency	Temperature	Power Factor
60 cps	25°C (77°F)	0.3%
	149°C (300°F)	0.64%
	155°C (311°F)	0.72%
1 kc	25°C (77°F)	0.5%
	100°C (212°F)	0.345%
1 mc	25°C (77°F)	1.6%
	155°C (311°F)	1.396%

Table 6.1. **Effect of frequency and temperature on Power Factor.** [Ref. 4] [Ref. 6]

Surface Resistivity

25° C,	0% R. H.	< 10^{17} ohms
25° C,	100% R. H.	4.8 x 10^{11} ohms

Table 7.1. **Effect of moisture on Surface Resistivity. Ref. 4**

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Volume Resistivity

25°C (77°F)	1×10^{19} ohm-cm
150°C (300°F)	1×10^{13} ohm-cm

Table 8.1. Effect of temperature on volume resistivity. [Ref. 4]

0 nvt	10^{15} ohm-cm
0.7×10^{18} nvt	10^{15} ohm-cm
1.2×10^{18} nvt	10^{12} ohm-cm

Table 8.2. Irradiation effects on volume resistivity. [Ref. 9]

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